

What is claimed is:

1        1. A method for robust single-pass variable bit rate video encoding, the method

2        comprising:

3                determining a buffer size for keeping track of over/underused bits generated

4                during the encoding of a video sequence, the buffer size being a function

5                of at least a target bit rate for the video sequence and a length of the video

6                sequence;

7                initializing the buffer to a default initial fullness; and

8                for each frame of the video sequence, performing the following steps:

9                allocating a number of bits to the frame;

10               determining a quant with which to encode the frame, the quant being a

11               function of at least the buffer's fullness;

12               encoding the frame according to the determined quant; and

13               updating the fullness of the buffer based on any over/underused bits for

14               the frame.

1        2. The method of claim 1 wherein frames in a GOP are encoded, the method further

2        comprising:

3                allocating a segment of the buffer for keeping track of over/underused bits for I

4                frames, a segment for keeping track of over/underused bits for P frames

5                and a segment for keeping track of over/underused bits for B frames;

6                initializing each segment of the buffer to a default initial fullness;

7 determining a number of I frames per GOP, a number of P frames per GOP and a  
8 number of B frames per GOP, based on a nominal GOP pattern;  
9 for each frame of the video sequence, determining the quant with which to encode  
10 that frame as a function of at least the fullness of the segment of the buffer  
11 for that frame type; and  
12 for each GOP of the video sequence, performing the following steps:  
13 before encoding any frame of that GOP, calculating a GOP bit target for  
14 that GOP, the GOP bit target being a function of at least the  
15 number of I frames, P frames and B frames per GOP, the target bit  
16 rate for the video sequence and any bits carried over from a last  
17 encoded GOP;  
18 after encoding each frame of that GOP, calculating over/underused bits by  
19 subtracting allocated bits from actual used bits, adding any  
20 over/underused bits to an appropriate buffer segment to an extent  
21 to which the appropriate buffer segment is not over/underflowed  
22 and storing any over/underflow bits in a counter; and  
23 after encoding all frames of that GOP, redistributing over/underused bits  
24 between the segments of the buffer as a function of at least a total  
25 number of over/underused bits in the buffer and the number of I  
26 frames, P frames and B frames per GOP and storing an indication  
27 of a number of over/underused bits with respect to the allocated  
28 target bits for that GOP to carry over to the next GOP.

- 1           3. The method of claim 2 further comprising:
- 2                 storing information concerning over/underused of at least some encoded frames
- 3                     by frame type; and
- 4                 using the stored information concerning over/underused bits of frames of a
- 5                     specific frame type in determining quants with which to encode frames of
- 6                     that type.
- 1           4. The method of claim 3 wherein storing information concerning over/underused of at
- 2                 least some encoded frames by frame type further comprises:
- 3                 storing information concerning over/underused of a specific number of most
- 4                     recently encoded I frames, P frames and B frames.
- 1           5. The method of claim 1 or 2, wherein:
- 2                 the buffer is a virtual buffer storing information concerning a number of
- 3                     over/underused bits, without storing the over/underused bits themselves.
- 1           6. The method of claim 2 further comprising:
- 2                 before encoding any frame, initializing to a default initial value at least one
- 3                     parameter from a group of parameters consisting of:
- 4                         a base quant envelope for each frame type;
- 5                         a base quant envelope control for each frame type;
- 6                         ratio information concerning frame types; and
- 7                         a frame complexity parameter for each frame type.

1           7. The method of claim 2 further comprising:

2                 for each GOP of the video sequence, before encoding any frame of that GOP,

3                     determining whether the fullness of each segment of the buffer is at least

4                         at an associated minimal value; and

5                 responsive to the fullness of a segment of the buffer not being at least at the

6                         associated minimal value, adjusting the fullness of the segment

7                         accordingly.

1           8. The method of claim 2 wherein allocating a number of bits to a frame further

2           comprises:

3                 allocating bits to the frame according to a modified TM5 reference model, the

4                     allocation utilizing at least one an additional parameter from a group of

5                         parameters consisting of:

6                 at least one frame complexity parameter for a last encoded frame of a frame type;

7                 a GOP bit target for the GOP being processed;

8                 ratio information concerning frame types within a GOP;

9                 the number of I frames per GOP;

10                 the number of P frames per GOP; and

11                 the number of B frames per GOP.

1           9. The method of claim 1 wherein allocating a number of bits to a frame further

2           comprises:

3                 allocating bits to the frame according to a TM5 reference model.

1        10. The method of claim 2 wherein determining a quant with which to encode the frame  
2 further comprises:

3              prior to determining the quant, normalizing the fullness of the segment  
4              corresponding to the type of frame to encode, based on at least the  
5              segment size and the non-normalized segment fullness; and  
6              determining the quant as a function of at least a base quant envelope and the  
7              normalized segment fullness.

1        11. The method of claim 10 further comprising:

2              adjusting the determined quant based on the frame being a transition frame in the  
3              video sequence.

1        12. The method of claim 1 further comprising:

2              after encoding each frame of the video sequence, determining whether the  
3              encoding of that frame causes a VBV buffer underflow;  
4              responsive to determining that the encoding of that frame causes a VBV buffer  
5              underflow, adjusting the quant used to encode the frame; and  
6              re-encoding the frame with the adjusted quant so as to eliminate the VBV buffer  
7              underflow.

1        13. The method of claim 2 further comprising:

2              after encoding each frame of the video sequence, updating at least one parameter  
3              from a group of parameters consisting of:  
4              a base quant envelope for the encoded frame type;

ratio information concerning frame types; and

a frame complexity parameter for the encoded frame type.

14. The method of claim 13 further comprising:

least a base quant envelope control for the encoded frame type, an indicator of the over/underflow bit status of the encoded frame, and the non-updated base quant envelope for the encoded frame type.

**15. The method of claim 10 further comprising:**

adding the counter of unallocated over/underflow bits to the buffer segment corresponding to the type of frame to encode, to an extent that the buffer segment is not overflowed or underflowed; and retaining any over/underflow bits that cannot be added to the segment in the counter.

16. A computer system for robust single-pass variable bit rate video encoding, the

**computer system comprising:**

means for determining a buffer size for keeping track of over/underused bits generated during the encoding of a video sequence, the buffer size being a function of at least a target bit rate for the video sequence and a length of the video sequence;

means for initializing the buffer to a default initial fullness; and

means for performing the following steps for each frame of the video sequence:

allocating a number of bits to the frame;

10 determining a quant with which to encode the frame, the quant being a  
11 function of at least the buffer's fullness;  
12 encoding the frame according to the determined quant; and  
13 updating the fullness of the buffer based on any over/underused bits for  
14 the frame.

1 17. The computer system of claim 16 wherein frames in a GOP are encoded, the  
2 computer system further comprising:  
3 means for allocating a segment of the buffer for keeping track of over/underused  
4 bits for I frames, a segment for keeping track of over/underused bits for P  
5 frames and a segment for keeping track of over/underused bits for B  
6 frames;  
7 means for initializing each segment of the buffer to a default initial fullness;  
8 means for determining a number of I frames per GOP, a number of P frames per  
9 GOP and a number of B frames per GOP, based on a nominal GOP  
10 pattern;  
11 means for determining the quant with which to encode that frame as a function of  
12 at least the fullness of the segment of the buffer for that frame type for  
13 each frame of the video sequence; and  
14 means for performing the following steps for each GOP of the video sequence:  
15 before encoding any frame of that GOP, calculating a GOP bit target for  
16 that GOP, the GOP bit target being a function of at least the  
17 number of I frames, P frames and B frames per GOP, the target bit

rate for the video sequence and any bits carried over from a last  
encoded GOP;  
after encoding each frame of that GOP, calculating over/underused bits by  
subtracting allocated bits from actual used bits, adding any  
over/underused bits to an appropriate buffer segment to an extent  
to which the appropriate buffer segment is not over/underflowed  
and storing any over/underflow bits in a counter; and  
after encoding all frames of that GOP, redistributing over/underused bits  
between the segments of the buffer as a function of at least a total  
number of over/underused bits in the buffer and the number of I  
frames, P frames and B frames per GOP and storing an indication  
of a number of over/underused bits with respect to the allocated  
target bits for that GOP to carry over to the next GOP.

18. The computer system of claim 17 further comprising:

means for storing information concerning over/underused of at least some encoded frames by frame type; and

means for using the stored information concerning over/underused bits of frames of a specific frame type in determining quants with which to encode frames of that type.

19. The computer system of claim 18 wherein the means for storing information

2 concerning over/underuse of at least some encoded frames by frame type further comprises:

3 means for storing information concerning over/underused of a specific number of  
4 most recently encoded I frames, P frames and B frames.

1 20. The computer system of claim 16 or 17, wherein:

2 the buffer is a virtual buffer storing information concerning a number of  
3 over/underused bits, without storing the over/underused bits themselves.

1 21. The computer system of claim 17 wherein the means for determining a quant with

2 which to encode the frame further comprises:

3 means for, prior to determining the quant, normalizing the fullness of the segment  
4 corresponding to the type of frame to encode, based on at least the  
5 segment size and the non-normalized segment fullness; and  
6 means for determining the quant as a function of at least a base quant envelope  
7 and the normalized segment fullness.

1 22. The computer system of claim 21 further comprising:

2 means for adding the counter of unallocated over/underflow bits to the buffer  
3 segment corresponding to the type of frame to encode, to an extent that the  
4 buffer segment is not overflowed or underflowed; and  
5 means for retaining any over/underflow bits that cannot be added to the segment  
6 in the counter.

1 23. The computer system of claim 16 further comprising:

2 means for, after encoding each frame of the video sequence, determining whether  
3 the encoding of that frame causes a VBV buffer underflow;

4 means for, responsive to determining that the encoding of that frame causes a  
5 VBV buffer underflow, adjusting the quant used to encode the frame; and  
6 means for re-encoding the frame with the adjusted quant so as to eliminate the  
7 VBV buffer underflow.

1 24. A computer system for robust single-pass variable bit rate video encoding, the

2 computer system comprising:

3 a portion configured to determine a buffer size for keeping track of  
4 over/underused bits generated during the encoding of a video sequence,  
5 the buffer size being a function of at least a target bit rate for the video  
6 sequence and a length of the video sequence;

7 a portion configured to initialize the buffer to a default initial fullness; and

8 a portion configured to perform the following steps for each frame of the video  
9 sequence:  
10 allocate a number of bits to the frame;

11 determine a quant with which to encode the frame, the quant being a

12 function of at least the buffer's fullness;

13 encode the frame according to the determined quant; and

14 update the fullness of the buffer based on any over/underused bits for the  
15 frame.

1 25. The computer system of claim 24 wherein frames in a GOP are encoded, the

2 computer system further comprising:

3           a portion configured to allocate a segment of the buffer for keeping track of  
4           over/underused bits for I frames, a segment for keeping track of  
5           over/underused bits for P frames and a segment for keeping track of  
6           over/underused bits for B frames;  
7           a portion configured to initialize each segment of the buffer to a default initial  
8           fullness;  
9           a portion configured to determine a number of I frames per GOP, a number of P  
10          frames per GOP and a number of B frames per GOP, based on a nominal  
11          GOP pattern;  
12          a portion configured to determine the quant with which to encode that frame as a  
13          function of at least the fullness of the segment of the buffer for that frame  
14          type for each frame of the video sequence; and  
15          a portion configured to perform the following steps for each GOP of the video  
16          sequence:  
17           before encoding any frame of that GOP, calculate a GOP bit target for that  
18           GOP, the GOP bit target being a function of at least the number of  
19           I frames, P frames and B frames per GOP, the target bit rate for the  
20           video sequence and any bits carried over from a last encoded GOP;  
21           after encoding each frame of that GOP, calculate over/underused bits by  
22           subtracting allocated bits from actual used bits, add any  
23           over/underused bits to an appropriate buffer segment to an extent  
24           to which the appropriate buffer segment is not over/underflowed  
25           and store any over/underflow bits in a counter; and

26 after encoding all frames of that GOP, redistribute over/underused bits  
27 between the segments of the buffer as a function of at least a total  
28 number of over/underused bits in the buffer and the number of I  
29 frames, P frames and B frames per GOP and store an indication of  
30 a number of over/underused bits with respect to the allocated target  
31 bits for that GOP to carry over to the next GOP.

1 26. The computer system of claim 25 further comprising:

2 a portion configured to store information concerning over/underused of at least  
3 some encoded frames by frame type; and  
4 a portion configured to use the stored information concerning over/underused bits  
5 of frames of a specific frame type in determining quants with which to  
6 encode frames of that type.

1 27. The computer system of claim 26 wherein the portion configured to store  
2 information concerning over/underused of at least some encoded frames by frame type further  
3 comprises:

4 a portion configured to store information concerning over/underused of a specific  
5 number of most recently encoded I frames, P frames and B frames.

1 28. The computer system of claim 24 or 25 wherein:

2 the buffer is a virtual buffer storing information concerning a number of  
3 over/underused bits, without storing the over/underused bits themselves.

1           29. The computer system of claim 25 wherein the portion configured to determine a  
2       quant with which to encode the frame further comprises:  
3                 a portion configured to, prior to determining the quant, normalize the fullness of  
4                 the segment corresponding to the type of frame to encode, based on at  
5                 least the segment size and the non-normalized segment fullness; and  
6                 a portion configured to determine the quant as a function of at least a base quant  
7                 envelope and the normalized segment fullness.

1           30. The computer system of claim 29 further comprising:  
2                 a portion configured to add the counter of unallocated over/underflow bits to the  
3                 buffer segment corresponding to the type of frame to encode, to an extent  
4                 that the buffer segment is not overflowed or underflowed; and  
5                 a portion configured to retain any over/underflow bits that cannot be added to the  
6                 segment in the counter.

1           31. The computer system of claim 24 further comprising:  
2                 a portion configured to, after encoding each frame of the video sequence,  
3                 determine whether the encoding of that frame causes a VBV buffer  
4                 underflow;  
5                 a portion configured to, responsive to determining that the encoding of that frame  
6                 causes a VBV buffer underflow, adjust the quant used to encode the  
7                 frame; and  
8                 a portion configured to re-encode the frame with the adjusted quant so as to  
9                 eliminate the VBV buffer underflow.

1           32. A computer readable medium containing a computer program product for robust  
2 single-pass variable bit rate video encoding, the computer program product comprising:  
3           program code for determining a buffer size for keeping track of over/underused  
4           bits generated during the encoding of a video sequence, the buffer size  
5           being a function of at least a target bit rate for the video sequence and a  
6           length of the video sequence;  
7           program code for initializing the buffer to a default initial fullness; and  
8           program code for performing the following steps for each frame of the video  
9           sequence:  
10           allocating a number of bits to the frame;  
11           determining a quant with which to encode the frame, the quant being a  
12           function of at least the buffer's fullness;  
13           encoding the frame according to the determined quant; and  
14           updating the fullness of the buffer based on any over/underused bits for  
15           the frame.

1           33. The computer program product of claim 32 wherein frames in a GOP are encoded,  
2 the computer program product further comprising:  
3           program code for allocating a segment of the buffer for keeping track of  
4           over/underused bits for I frames, a segment for keeping track of  
5           over/underused bits for P frames and a segment for keeping track of  
6           over/underused bits for B frames;

7 program code for initializing each segment of the buffer to a default initial  
8 fullness;  
9 program code for determining a number of I frames per GOP, a number of P  
10 frames per GOP and a number of B frames per GOP, based on a nominal  
11 GOP pattern;  
12 program code for determining the quant with which to encode that frame as a  
13 function of at least the fullness of the segment of the buffer for that frame  
14 type for each frame of the video sequence; and  
15 program code for performing the following steps for each GOP of the video  
16 sequence:  
17 before encoding any frame of that GOP, calculating a GOP bit target for  
18 that GOP, the GOP bit target being a function of at least the  
19 number of I frames, P frames and B frames per GOP, the target bit  
20 rate for the video sequence and any bits carried over from a last  
21 encoded GOP;  
22 after encoding each frame of that GOP, calculating over/underused bits by  
23 subtracting allocated bits from actual used bits, adding any  
24 over/underused bits to an appropriate buffer segment to an extent  
25 to which the appropriate buffer segment is not over/underflowed  
26 and storing any over/underflow bits in a counter; and  
27 after encoding all frames of that GOP, redistributing over/underused bits  
28 between the segments of the buffer as a function of at least a total  
29 number of over/underused bits in the buffer and the number of I

30 frames, P frames and B frames per GOP and storing an indication  
31 of a number of over/underused bits with respect to the allocated  
32 target bits for that GOP to carry over to the next GOP.

1 34. The computer program product of claim 32 further comprising:  
2 program code for storing information concerning over/underused of at least some  
3 encoded frames by frame type; and  
4 program code for using the stored information concerning over/underused bits of  
5 frames of a specific frame type in determining quants with which to  
6 encode frames of that type.

1 35. The computer program product of claim 34 wherein the program code for storing  
2 information concerning over/underused of at least some encoded frames by frame type further  
3 comprises:

4 program code for storing information concerning over/underused of a specific  
5 number of most recently encoded I frames, P frames and B frames.

1 36. The computer program product of claim 32 or 33 wherein:  
2 the buffer is a virtual buffer storing information concerning a number of  
3 over/underused bits, without storing the over/underused bits themselves.

1 37. The computer program product of claim 33 wherein the program code for  
2 determining a quant with which to encode the frame further comprises:

3 program code for, prior to determining the quant, normalizing the fullness of the  
4 segment corresponding to the type of frame to encode, based on at least  
5 the segment size and the non-normalized segment fullness; and  
6 program code for determining the quant as a function of at least a base quant  
7 envelope and the normalized segment fullness.

1 38. The computer program product of claim 37 further comprising:  
2 program code for adding the counter of unallocated over/underflow bits to the  
3 buffer segment corresponding to the type of frame to encode, to an extent  
4 that the buffer segment is not overflowed or underflowed; and  
5 program code for retaining any over/underflow bits that cannot be added to the  
6 segment in the counter.

1 39. The computer program product of claim 32 further comprising:  
2 program code for, after encoding each frame of the video sequence, determining  
3 whether the encoding of that frame causes a VBV buffer underflow;  
4 program code for, responsive to determining that the encoding of that frame  
5 causes a VBV buffer underflow, adjusting the quant used to encode the  
6 frame; and  
7 program code for re-encoding the frame with the adjusted quant so as to eliminate  
8 the VBV buffer underflow.